

base of the clouds could be seen to become lower until it obscured the tops of the high buildings, then the lower buildings, and finally rested on the surface and appeared in all respects like true fog. As this occurred at night it was possible to see the base of the cloud as it approached the street lights, and it was observed to be very irregular and ill-defined. Such fogs generally do not last more than two or three hours. When they clear they sometimes do so from the bottom up and again from the top down, i. e., in the former the cloud clears at the surface but continues aloft, while in the latter the top either clears, or descends, until the surface is reached and the sky remains clear the remainder of the night. The latter condition was observed more frequently than the former. If a sharp base is known to be at 1,000 or 1,200 feet, or less, and the relative humidity at the surface somewhat above normal, fog is to be expected that night.

It hardly seems necessary to mention that the presence of a considerable amount of high clouds, either cirro or alto clouds, greatly retards the forming and burning off of the velo cloud. However, this is a fact and must be considered by the forecaster when attempting to answer some of the whens he is asked.

The flights and observations described above were made largely because of the belief that if the inversion and the velo cloud were more fully understood, the explanation of the various types of weather would follow. Although it was impossible to verify many of the following contentions, it is believed that the principles set forth in the preceding paragraphs satisfactorily explain many of the perplexing questions which confront the forecaster along the California coast. Among the most important of these may be mentioned (a) the existence of the inversion with deep westerly winds as well as with winds from land; (b) why the velo cloud forms; (c) why it is typically a night cloud; (d) why it occurs over the ocean so much more frequently than over the land; (e) why it frequently

does not burn off at sea; (f) why the base frequently rises during the night; (g) why the cloudiness sometimes increases for several days and then decreases during the next several days (occasionally the clouds will disappear entirely within 24 to 48 hours and the resulting clear weather will continue for several days); (h) why fog is almost sure to develop along the coast and for several miles inland on nights when the base is less than 1,200 feet high, especially when the temperature above the base increases rapidly; (i) why this type of fog clears over the land within a few hours, sometimes from the ground up, but more often "from the top down"; and why a light mist sometimes falls in the early morning during the summer.

It is recognized that the observations made in 1929 are but the beginning of those necessary to solve the riddle of the irregularities of California's regular weather, but it is felt that useful, as well as interesting, information has been obtained. It is seen that the aerograph has become much more helpful to the forecaster because, by means of it, he is supplied with such very useful information, as, the height of the base, the amount and sharpness of the inversion, the humidity above the base, and the lapse rate and distribution of moisture below the base. All of these data are of practical value in forecasting local weather and, in all probability, will become more so as additional facts are learned since, even with the imperfect ideas held during this investigation, the thickness of the morning velo cloud and the height of the base were forecast several times from the afternoon aerograph record and the Neuhoff chart. It is granted that this was largely the result of chance, since the assumptions made were only guesses. Still there appear to be no good reasons why, with additional knowledge, not only the height and thickness of the clouds and the height of the base, but also the other features which are of vital importance to the aviator and navigator will be forecast with confidence and accuracy.

## SOUTHERN ARIZONA FLYING WEATHER

By LEON C. WALTON

[Weather Bureau Office, Phoenix, Ariz.]

Science and invention have accomplished considerable in recent years to further the cause of aviation. Equipment has been improved and many valuable lessons learned, often at great cost, so that aerial navigation has been stripped of most of its perils. In flying circles, the weather remains a favorite topic but even that has been shorn of its terror, not because we can defy or control the elements, but due to the excellent system of reporting and forecasting conditions as they are and as they will be a few hours or days hence.

No section of the country enjoys "perfect" weather, but southern Arizona is probably as free from weather hazards as is any locality in the United States.

The route selected by the Southern Transcontinental Airline from El Paso, Tex., via Douglas, Tucson, and Phoenix, Ariz., to Los Angeles, Calif., traverses a flat open terrain, with the exception of a low range of mountains near the Arizona-New Mexico boundary, and a scattering of hills, some of which have been dignified by the name of "mountain." Throughout the greater portion of the year, a pilot flying over this territory at an altitude exceeding 1,500 feet is in a realm where the visibility is limited only by the power of his own eye. Haze, smoke, fog, low clouds, and other limiting agents are of such rare occurrence as to be almost negligible.

Snow, sleet, and ice are practically unknown, and the only place they could occur would be in the upper reaches over the only range of mountains crossed.

Dense fog, so feared in many localities, seldom obscures the Arizona landscape. It has been observed only 36 times in the past twenty years at the Phoenix Weather Bureau office, and the distribution by months leaves most of the year fog free. December leads with 20; January follows with 11; November supplies 4; and March furnishes the other day with dense fog. Five of the twenty years have had none at all. During the winter months an occasional blanket of smoke partially obscures the city of Phoenix but leaves the airport clear. At Douglas, Ariz., the smoke occasionally cuts the visibility to as little as 3 miles, but is never dense enough to offer a serious handicap to flying, as the "blanket" is not more than 300 or 400 feet in thickness.

Another indication of the excellent visibility is the fact that the beacons between Phoenix and Los Angeles are located about 30 miles apart. East of Phoenix the airway is not yet lighted but when installation is completed the average distance between beacons from Dallas to Los Angeles will be as nearly uniform as possible.

Ceilings are usually unlimited, or at least, sufficient to allow a generous margin of safety. In time of precipi-

tation estimated ceilings less than 1,000 feet have been reported, but the lowest ceiling encountered by a pilot balloon is 1,125 meters, or 3,700 feet.

With fair weather the prevailing condition, flight schedules are seldom interfered with. Occasional unfavorable weather at the coast terminal delays a plane's departure, but cancellations are few. During the eight months of airmail in this section, only about 15 flights have been canceled due to Arizona weather, most of these occurring during February of this year.

In line with its policy of cooperation and expansion, the Weather Bureau inaugurated pilot balloon work at the Phoenix Weather Bureau office in February, 1930, and the data thus obtained played an important rôle in preparing schedules for the air mail which began eight months later.

The upper-air data herewith presented have been prepared from the results of the first year's observations, i. e., to January 31, 1931. Only the regular morning and evening runs have been considered, of which there have been 696 out of a possible 708, or 98.2 per cent. Only 5 of the 12 runs omitted were missed on account of the weather. Surface data are not included in the accompanying tables, being deemed of insufficient value to justify the time necessary for its preparation. The surface wind at the morning observation is light to gentle easterly with surprising regularity, while that at the afternoon run is usually light to gentle variable. The exceptions to both of these generalities would not be sufficient to affect the averages. Four levels have been selected for study, namely: 1,000, 2,000, 3,000, 4,000 meters above sea-level, and it is interesting to note that these levels were reached by 696, 694, 624, and 446 balloons, respectively. Thus, only 70 runs failed to supply data as high as the 3,000 meter level. The large decrease between the 3,000 and 4,000 meter levels is caused by the use of lanterns for the morning observations.

TABLE 1.—1,000 meters above sea level

[Velocities in meters per second; fractions omitted]

|          | Summer |                  |        |                  | Winter |                  |        |                  |
|----------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|
|          | A. M.  |                  | P. M.  |                  | A. M.  |                  | P. M.  |                  |
|          | Number | Average velocity | Number | Average velocity | Number | Average velocity | Number | Average velocity |
| N.....   | 11     | 2                | 2      | 3                | 7      | 4                | 5      | 2                |
| NNE..... | 2      | 4                | 5      | 2                | 7      | 5                | 4      | 4                |
| NE.....  | 7      | 3                | 3      | 3                | 10     | 4                | 6      | 2                |
| ENE..... | 7      | 4                | 0      | 0                | 32     | 6                | 6      | 4                |
| E.....   | 8      | 3                | 0      | 0                | 22     | 7                | 14     | 4                |
| ESE..... | 13     | 6                | 7      | 2                | 20     | 6                | 20     | 5                |
| SE.....  | 9      | 6                | 8      | 4                | 7      | 4                | 7      | 5                |
| SSE..... | 6      | 4                | 4      | 5                | 3      | 5                | 6      | 2                |
| S.....   | 7      | 6                | 5      | 3                | 6      | 8                | 9      | 5                |
| SSW..... | 7      | 3                | 7      | 4                | 7      | 3                | 7      | 7                |
| SW.....  | 8      | 6                | 13     | 3                | 14     | 4                | 12     | 4                |
| WSW..... | 27     | 5                | 36     | 5                | 6      | 3                | 16     | 4                |
| W.....   | 30     | 4                | 47     | 6                | 12     | 5                | 20     | 5                |
| WNW..... | 15     | 5                | 27     | 4                | 4      | 3                | 18     | 5                |
| NW.....  | 11     | 4                | 10     | 3                | 3      | 13               | 6      | 3                |
| NNW..... | 9      | 3                | 3      | 2                | 4      | 3                | 7      | 3                |

The following tables, numbered 1, 2, 3, and 4, present the results of these 696 observations. The division into summer and winter include April 1 to September 30, and October 1 to March 31, respectively. The first column under each season gives the total number of times the wind blew from the directions indicated regardless of velocity. Otherwise the various headings are self-explanatory. Originally, it was planned to include the wind

resultants for each season, but as these data are already on file, by months, at the Weather Bureau offices in both Washington, D. C., and Phoenix, Ariz., available to those who may have special need thereof, this plan was abandoned in favor of the less technical one presented in this paper.

TABLE 2.—2,000 meters above sea level

[Velocities in meters per second; fractions omitted]

|          | Summer |                  |        |                  | Winter |                  |        |                  |
|----------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|
|          | A. M.  |                  | P. M.  |                  | A. M.  |                  | P. M.  |                  |
|          | Number | Average velocity | Number | Average velocity | Number | Average velocity | Number | Average velocity |
| N.....   | 7      | 2                | 3      | 4                | 11     | 4                | 13     | 6                |
| NNE..... | 6      | 2                | 2      | 2                | 7      | 7                | 11     | 6                |
| NE.....  | 2      | 2                | 2      | 2                | 6      | 5                | 11     | 7                |
| ENE..... | 5      | 3                | 7      | 3                | 14     | 5                | 13     | 6                |
| E.....   | 8      | 4                | 5      | 2                | 11     | 6                | 13     | 8                |
| ESE..... | 7      | 4                | 6      | 4                | 17     | 6                | 12     | 7                |
| SE.....  | 10     | 5                | 4      | 4                | 10     | 6                | 3      | 5                |
| SSE..... | 8      | 6                | 9      | 5                | 6      | 8                | 8      | 5                |
| S.....   | 24     | 7                | 17     | 7                | 7      | 7                | 9      | 8                |
| SSW..... | 15     | 7                | 24     | 6                | 10     | 7                | 15     | 6                |
| SW.....  | 17     | 5                | 23     | 6                | 20     | 5                | 10     | 8                |
| WSW..... | 19     | 6                | 25     | 6                | 9      | 8                | 11     | 7                |
| W.....   | 15     | 4                | 21     | 5                | 7      | 8                | 11     | 7                |
| WNW..... | 14     | 4                | 15     | 5                | 9      | 6                | 8      | 7                |
| NW.....  | 11     | 5                | 6      | 4                | 14     | 6                | 7      | 5                |
| NNW..... | 8      | 2                | 4      | 5                | 8      | 5                | 9      | 5                |

TABLE 3.—3,000 meters above sea level

[Velocities in meters per second; fractions omitted]

|          | Summer |                  |        |                  | Winter |                  |        |                  |
|----------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|
|          | A. M.  |                  | P. M.  |                  | A. M.  |                  | P. M.  |                  |
|          | Number | Average velocity | Number | Average velocity | Number | Average velocity | Number | Average velocity |
| N.....   | 7      | 5                | 5      | 5                | 8      | 10               | 14     | 11               |
| NNE..... | 6      | 4                | 3      | 4                | 2      | 6                | 12     | 7                |
| NE.....  | 2      | 4                | 6      | 4                | 7      | 7                | 7      | 5                |
| ENE..... | 2      | 2                | 5      | 3                | 9      | 7                | 13     | 8                |
| E.....   | 5      | 6                | 6      | 4                | 6      | 7                | 12     | 9                |
| ESE..... | 6      | 7                | 8      | 6                | 6      | 6                | 5      | 10               |
| SE.....  | 4      | 3                | 7      | 4                | 4      | 5                | 5      | 7                |
| SSE..... | 8      | 5                | 13     | 6                | 4      | 6                | 6      | 7                |
| S.....   | 27     | 9                | 18     | 9                | 7      | 10               | 7      | 8                |
| SSW..... | 28     | 9                | 24     | 9                | 6      | 8                | 9      | 11               |
| SW.....  | 21     | 9                | 34     | 9                | 20     | 9                | 11     | 9                |
| WSW..... | 16     | 10               | 32     | 7                | 10     | 7                | 12     | 11               |
| W.....   | 9      | 4                | 20     | 6                | 13     | 9                | 4      | 9                |
| WNW..... | 2      | 4                | 9      | 4                | 7      | 8                | 14     | 8                |
| NW.....  | 6      | 5                | 7      | 7                | 12     | 8                | 7      | 9                |
| NNW..... | 3      | 5                | 7      | 4                | 18     | 8                | 14     | 9                |

Referring to Table 1, it will be noted that during the summer, the prevailing direction is west, or points immediately adjacent thereto, and in the case of the morning observations, is in striking contrast to surface winds. Experience has shown that these surface easterlies are very shallow, the balloons frequently encountering opposing or cross currents a few seconds after being released. During the winter, this lower stratum of westbound atmosphere is somewhat thicker, extending to the 1,000-meter level with greater frequency. In the afternoon, throughout the year, the western quadrant supplies the greater portion of the winds. The range in velocities is small, so the averages listed are truly representative.

Inspection of Table 2, reveals the fact that the prevailing easterlies in the previous level are caused by conditions more local than general, as their influence apparently barely extends to the 2,000-meter level. That they

are more prevalent in the winter than in the summer would indicate that the temperature is vitally important in their existence. In this higher level we find southwest predominating, although the range is from south to west. This is especially true in the summer, as in the winter the winds are more variable. Velocities are higher and, although the increase is not great in summer, there is a tendency toward stronger winds, particularly in the cooler months of the year.

TABLE 4.—4,000 meters above sea level  
(Velocities in meters per second; fractions omitted)

|          | Summer      |                               |             |                               | Winter      |                               |             |                               |
|----------|-------------|-------------------------------|-------------|-------------------------------|-------------|-------------------------------|-------------|-------------------------------|
|          | A. M.       |                               | P. M.       |                               | A. M.       |                               | P. M.       |                               |
|          | Num-<br>ber | Aver-<br>age<br>veloc-<br>ity | Num-<br>ber | Aver-<br>age<br>veloc-<br>ity | Num-<br>ber | Aver-<br>age<br>veloc-<br>ity | Num-<br>ber | Aver-<br>age<br>veloc-<br>ity |
| N.....   | 3           | 7                             | 9           | 3                             | 3           | 7                             | 17          | 9                             |
| NNE..... | 3           | 10                            | 6           | 5                             | 3           | 3                             | 4           | 11                            |
| NE.....  | 1           | 3                             | 4           | 8                             | 11          | 7                             | 5           | 8                             |
| ENE..... | 2           | 6                             | 3           | 3                             | 2           | 8                             | 12          | 9                             |
| E.....   | 3           | 6                             | 1           | 11                            | 0           | 0                             | 5           | 8                             |
| ESE..... | 2           | 2                             | 6           | 6                             | 2           | 3                             | 3           | 7                             |
| SE.....  | 3           | 4                             | 4           | 4                             | 0           | 0                             | 4           | 4                             |
| SSE..... | 5           | 6                             | 9           | 5                             | 3           | 7                             | 2           | 6                             |
| S.....   | 5           | 9                             | 11          | 10                            | 0           | 0                             | 6           | 6                             |
| SSW..... | 14          | 12                            | 16          | 11                            | 0           | 0                             | 8           | 9                             |
| SW.....  | 14          | 10                            | 29          | 9                             | 5           | 12                            | 10          | 10                            |
| WSW..... | 13          | 10                            | 26          | 10                            | 4           | 15                            | 16          | 12                            |
| W.....   | 6           | 8                             | 14          | 8                             | 5           | 19                            | 4           | 14                            |
| WNW..... | 5           | 7                             | 12          | 6                             | 5           | 8                             | 16          | 10                            |
| NW.....  | 4           | 5                             | 4           | 6                             | 11          | 14                            | 12          | 14                            |
| NNW..... | 2           | 6                             | 10          | 3                             | 8           | 12                            | 10          | 15                            |

The conditions found at 2,000 meters extend upward through the other two levels, with an ever improving advantage to the eastbound flier. During the summer the sector south to west prevails, while during winter, the directions are from west to north.

Briefly, then, the fact that Phoenix has a greater number of easterly surface winds does not indicate that the upper currents differ from those over the country in general. On the contrary, we find that the movement is from the western portion of the compass. However, the

upper winds cover a wider range of directions than are found to exist in many sections of the United States. This may be due to the location of Phoenix at a point considerably south of the usual paths of the cyclones and anticyclones.

Upper-air investigation has revealed several interesting features of the atmosphere in this region. Surface winds are usually light, and, particularly on hot afternoons, this "stagnation" often extends to considerable altitude. Balloons have been followed to 4,000 meters and 5,000 meters with elevation angles remaining above 60°. Graphs of such runs show every point of the compass.

*Estimating ceiling or cloud height.*—Most observers learn to associate cloud formations with altitudes, so when one is known, the other can be more readily estimated. Such individuals face a problem in this locality until the acquisition of sufficient data warrants definite estimates. Of the 1,150 balloon runs made to date, cloud altitudes have been ascertained in exactly 100 instances, but these, with 3 exceptions have been confined to 3 cloud types. Strato-cumulus lead in frequency, ranging in altitude above the surface from 1,100 to 4,200 meters, with an average of 2,250 meters. The two remaining types share equally as to frequency but show considerable variation in altitude. Alto-cumulus range from 2,400 to 6,400 meters with an average of 3,700 meters, as compared with an average of 5,400 meters for alto-stratus, which showed a range from 4,000 to 8,000 meters. Comparison with the cloud altitude charts in common use indicates that clouds in southern Arizona average somewhat higher than in other portions of the country.

Everything considered, flying conditions are very favorable in this section. An average of only 41 cloudy days, 39 of which with a measureable amount of precipitation, per year; no ice-forming weather; no snow; very little fog; and very few high winds, 43 miles per hour being a 35-year maximum, are some of the outstanding reasons why this has been designated "the fair weather route." Add to this the favorable upper winds as outlined above, and this locality's desirability as a flying center can be readily appreciated.

## DIMINISHING WINTER RADIATION FROM SUN AND SKY AT MADISON, WIS.

By ERIC R. MILLER

[Weather Bureau, Madison, Wis.]

A continuing decrease of the insolation registered at Madison with the Callendar bolometric sunshine recorder was pointed out by Mr. A. F. Piippo (1) and the question whether it was due to city smoke or to deterioration of the apparatus was considered by Dr. H. H. Kimball in a note to the same paper. The present paper adds further data and applies statistical methods to their interpretation.

Smokiness in Madison is mostly due to heating, since the city is administrative, educational, and residential rather than industrial. The few industrial plants are located 3 or 4 miles east of the Weather Bureau station, and the prevailing winds are northwest in winter, southwest in summer. The university heating plant with chimney 250 feet high is 1,000 feet south-southwest of the station. Its annual consumption of coal (in tons of 2,000 pounds) in years ending June 30, was:

|              | Tons    |              | Tons    |
|--------------|---------|--------------|---------|
| 1912-13..... | 19, 576 | 1922-23..... | 20, 649 |
| 1913-14..... | 20, 489 | 1923-24..... | 21, 693 |
| 1914-15..... | 19, 640 | 1924-25..... | 21, 076 |
| 1915-16..... | 20, 039 | 1925-26..... | 24, 773 |
| 1916-17..... | 22, 986 | 1926-27..... | 25, 963 |
| 1917-18..... | 18, 670 | 1927-28..... | 28, 463 |
| 1918-19..... | 22, 162 | 1928-29..... | 30, 554 |
| 1919-20..... | 20, 429 | 1929-30..... | 30, 153 |
| 1920-21..... | 19, 183 | 1930-31..... | 29, 446 |
| 1921-22..... | 19, 997 |              |         |

The smoke from this chimney always drifts off in a compact stream before diffusing. The proportion of black smoke has been greatly decreased in recent years by improvements in the furnaces to bring about complete combustion. It is not possible to present similar statistics of the use of coal for domestic heating. A notion of the change is afforded by the census reports of the population